QUEST

Quality and Energy efficiency in Storage and Transport of agro-materials

Progress report
September 2002 – March 2003

Ref.nr. OPD 01/350/060503

Confidential

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ATO

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1 Progress

1.1 Activities in relation with planning last half year

The project deliverables are:
1. Selection of products and markets for the new container concept considering:
   - Potential for energy reduction
   - Benefits of improved product quality
   - Benefits of monitoring product status and product quality
2. Market introduction strategy building market acceptance
3. Predictive models of the agro-product describing the relation between:
   - Climate conditions and energy consumption
   - Product history and transport conditions prior to transport/storage in relation to product quality
   - Climate conditions and product responses
4. Monitoring system consisting of:
   - Measurement of product response such as respiration, fermentation, ethylene and water loss and climate conditions
   - Estimation of product status and product quality in relation to climate conditions and energy usage using the predictive models
5. Control system consisting of:
   - Hardware improvements to efficiently cope with the optimised climate settings and measure product response
   - Software algorithms calculating most efficient climate conditions
6. Practical guidelines establishing:
   - Quality requirements for the product
   - Effects of packaging and stowage patterns in relation to effective climate conditions
7. Chain information and technology transfer dealing with:
   - Establishing necessary and beneficial chain information
   - Evaluation possibilities for transfer of sustainable technologies to storage facilities and inland transport
   - Evaluation of possibilities for reduction of energy consumption in existing storage facilities

During the inventory phase two different modules for climate control have been defined; QUEST regular and QUEST pro. QUEST regular is defined as the module for climate control in which set-points for temperature, variation in temperature, gas conditions and humidity are based both on a calculation of energy consumption for climate conditioning and on product requirements for optimal quality. Taking into account the effect of climate on product in transport, the effect on quality during shelf life and the variation in initial quality. In addition to that, in QUEST pro climate control includes feed back from a monitoring system for product response to determine the set points for temperature, gas conditions and humidity.

The key milestones of the QUEST project are:
Inventory phase (September 2002 - March 2003)
- February 2003: Test prototype Quest-regular controller at container level (at ATO, no full load)

Research phase (March 2003 - September 2004)
- July 2003: full scale container tests with Quest-regular controller, Dutch produce

- February 2004: full scale container tests with Quest-regular controller, foreign produce
- August 2004: Test prototype Quest-pro controller at container level (at ATO, no full load)

Integration phase (September 2004 – September 2005)

- February 2005: full scale container tests with Quest-pro controller

The milestones of the project are described in more detail in appendix 1.

The milestones for the Inventory phase were defined as follows:

1. Selection of products and markets
   - Select products (market share, profit, feasibility)
2. Market introduction strategy
   - Definition unique selling points (energy, product knowledge)
   - Define relevant results from Pilot test: contact parties relevant for market introduction (relevant partners, relevant markets)
3. Predictive models
   - Energy saving options (circulation, ventilation, defrost)
   - Temperature differences in space and time (effects of box, stowage)
   - Effects on product (cycling, condensation, weight loss, other quality aspects)
4. Monitoring system
   - What to measure (weight loss, ethylene, respiration)
   - How to measure (moisture balance, Electro chemical)
5. Control system
   - Structure ready (possibilities to use for other parameters)
   - Stable controller (the controller in control, instead of the operator)
6. Practical guidelines
   - Choose design tool ("chain oriented design")
   - Determine set-up (web interface, book, table)
   - Interaction with researchers (relevant data/models for guidelines)
7. Chain information and technology transfer
   - Inventory present situation (what is happening now)
   - Options for application of new technology (where can Quest knowledge be introduced)
8. Testing and integration
   - Test prototype Quest-regular controller at ATO

The main activities in the different tasks in the Inventory phase were the following:

1. Selection of products and markets

Products have been selected for the first full-scale tests.

- Bell peppers for export from the Netherlands with QUEST-regular controller
- Avocado for import to the Netherlands with QUEST-regular

2. Market introduction strategy

PON and ERBS have reached an agreement on the conduction of market introduction research by ERBS. A detailed planning has been made for the market introduction strategy. This has been written down in the discussion document 'QUEST Selection of products and markets, and market introduction strategy, discussion document'. This document describes how within the Quest project a market introduction plan can be developed. The document describes the conceptual approach, work of action and the roles of various participants.

3. Predictive models

The models developed in the previous project predicting energy consumption and climate of a refrigerated container have been used to discuss opportunities for energy savings. Compressor cycling control turns out to be a promising option for reduction of energy use.

The results of the modelling studies have been discussed during the Progress Meeting on 30 January 2003.

A literature/database study has been conducted on temperature set points and variation in temperature for a broad range of products. This has resulted in a first classification of products in which categories are based on a similar type of control of temperature and ventilation. The results of this study have been discussed during the Progress Meeting on 30 January 2003.

4. Monitoring system

For the monitoring system, work of the previous project on estimation of respiration rates is continued. An abstract has been submitted for the conference 'Quality In Chains', An Integrated View on Fruit and Vegetable Quality, in Wageningen on 6-9 July 2003. The paper deals with monitoring produce quality in reefer containers by estimation of respiration.
A feasibility study on the development of an ethylene sensor and weight loss sensor is carried out. For ethylene a new, relatively cheap sensor is commercially available.
A set-up for lab scale testing of interactive control using a monitoring system is being built. This set-up will be used for testing the Quest-pro control principle.

5. Control system

For the first full-scale test at ATO starting in March 2003 energy saving control software has been developed and linked to the hardware. Actual energy savings have been measured and the robustness of the communication has been tested. ATO and Carrier have exchanged information on the control system during visits of ATO to Carrier in Rotterdam and Syracuse.

6. Practical guidelines

For the development of practical guidelines a number of questions on type of information, form (web-site, table etc.) and the use/users of the information needs to be answered by the commercial partners. The Practical Guidelines were discussed during the Progress Meeting on 30 January. The discussion about the practical guidelines will be continued.

7. Chain information and technology transfer

A detailed work plan is being discussed between ATO and The Greenery.

8. Testing and integration

In a first full-scale test the Quest-regular controller has been tested in a partially loaded container. To simulate the effect of a full load, artificial air humidification and heat production was used. The results of the test were discussed during the Management Meeting on 27 March. Preparations are being made for the first full-scale test in real transport in July: a shipment of bell peppers from Rotterdam to New York.

From the activities mentioned above it can be seen that the key milestones of the inventory phase have been reached. Only for the practical guidelines, there is no final decision about the desired output or form.

1.2 Costs in relation with planning last half year

The costs realised in the period from 1 September 2002 to 1 March 2003 are € 626.159 and the requested subsidy is € 374.348. This is exclusive of the costs made by Frugi Venta and the Greenery. These expenses will be submitted in September, after the next half-year period. R&R Mechatronics has not made costs in the first period.

In total approximately 10% of the total costs of the project has been realised. ATO has realised approximately 20% of its total budget. It is expected that in the course of the project the relative contribution of the companies to the project will increase.

1.3 Milestones next half year

The milestones for the next half-year are:

1. QUEST-regular
   - experimental/literature research on set points
   - spatial variation/effects of stowage and packaging
   - controller tested in full scale pilot test (shipment of bell-peppers from Rotterdam to New-York)

2. QUEST-pro
   - selection of products
   - selection of sensors
   - preparation lab scale testing

2 Results

2.1 Main results

Classification of products
To determine whether various groups of fresh products behave in a similar way to transport conditions (i.e. temperature, controlled atmosphere conditions, RH, ethylene) a classification was made. Effects of harvest period, orchard and cultivar on transport conditions were not considered. 42 Fresh commodities with the largest contribution to the maritime transport volume in 2000 were classified with regard to:

- transport temperature,
- the effect of CA on product quality,
- the ethylene sensitivity and ethylene production,
- the maximum transit time + shelf life time.

Almost all commodities that are highly ethylene sensitive benefit from transport under CA conditions with the exception of mango, cucumber and papaya (see classification table). Apple, pear and plum are sensitive to ethylene but can be transported without CA conditions depending on the required transport time. Quality decay (firmness) of these products normally starts after the climacteric ethylene production phase is reached. A group of commodities that is stored at low temperature (-1 and 4°C) and are insensitive to ethylene also benefit from CA conditions. In this group, some products are found which have either a high relative respiration rate (artichoke, asparagus) or are very susceptible to spoilage by micro-organisms (i.e. strawberry).

A group of commodities that is transported in the medium temperature range (8-10°C) are, with a few exceptions (avocado, cucumber and mango), insensitive to ethylene and do not benefit from CA transport. Quality decay within this group is often closely related to water loss. Most products that are transported in the medium temperature range can be transported for more than 2 weeks.

In the high temperature range (above 12°C) three products (banana, tomato and papaya) are found which are highly sensitive to ethylene, depending on the ripening stage. Therefore these do not always benefit from storage under CA conditions. Some of the processes related to their quality loss (firmness loss, spoilage) are not influenced by ethylene.

Based on this classification it may be interesting to consider whether products that are placed in one category behave similar to variations in transport conditions (T, RH, and ventilation).

To obtain priorities, information is added on trade volumes ($), based on data from P&O Nedlloyd. For the testing phases, products will be chosen that generate the larger trade volumes.

1000$	color coding
< 100000	
>100000; < 500000	
>500000; <1000000	
>1000000	

		Ethylne	transit time and shelf life	
temperature	CA effect	sensitive	>2 wks	< 2 wks
low -1 / -4 C	high	H	[redacted]	apricot
			peach/nect	
			pear	
			Cabage	Lettuce
			Kiwi fruit	
			Plum	
		M+L	Atrichoke	Cherry (sour)
			Asparagus	Cherry (sweet)
			Garlic	Fig
			Onion	Strawberry
	low	H	Cauliflower	Spinache
			Chinese Cabbage	
		M+L	[redacted]	Mushroom
			Carrot	

		Ethylne	transit time and shelf life	
temperature	CA effect	sensitive	>2 wks	< 2 wks
8/10 C	high	H	Avocado	
	Low	H	Mango	Cucumber
		M+L	Grapefruit	bell pepper
			Olive	green bean
			Orange	tomato
			Pineapple	egg plant
			Potato	
			Watermelon	

		Ethylne	transit time and shelf life	
temperature	CA effect	sensitive	>2 wks	< 2 wks
>12	high	H	[redacted]	
			tomato (green)	
		M+L	lemon	
	low	H	papaya	

Full-scale Container test

In a first full-scale test the Quest-regular controller has been tested in a partially loaded container, with two pallets of bell-peppers. Aim of this test was to test the controller and at the same time test how energy consumption of the unit and product quality in the container are affected by a cycling cooling regime compared to a standard cooling regime.

Climate control and reduction of energy use

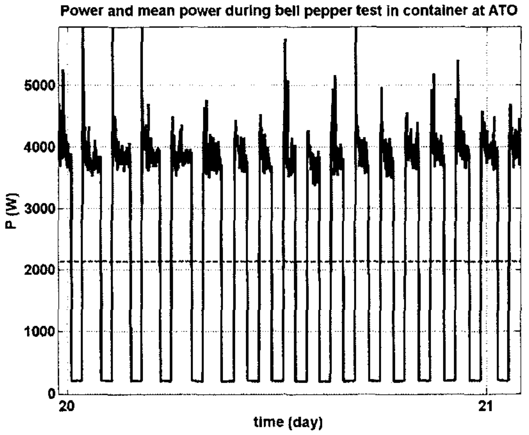
The design of the controller was made using models on container climate, energy consumption of the unit for climate conditioning and product behaviour. The boundary conditions used in the design of the controller are a mean relative humidity of 92%, a mean product temperature of 9.2°C and a CO_2-concentration of <1%. Ventilation was set to a low value of 5 m^3/h to prevent condensing while the compressor was switched off.

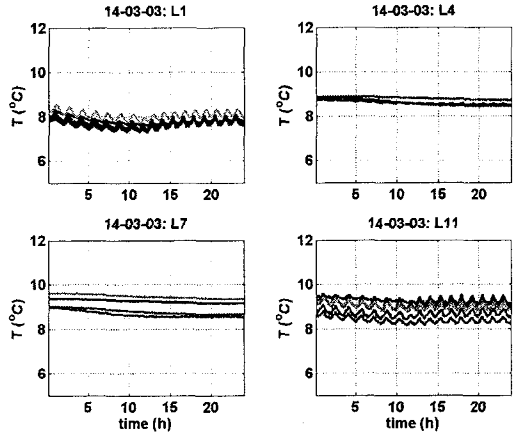
To achieve a reduction in energy use, variation in temperature was allowed by compressor cycling and reduced air circulation. The supply air was 6°C when the compressor was switched on, and increased to temperatures slightly above that of the return air when the compressor was switched off. The return air ranged between 8.5 and 10.5°C. Model calculations showed that compressor cycling, the more efficient way of cooling, should give a reduction in power consumption of 1 kW. Together with the reduced fan speed energy savings were calculated to be >50 %.

In the full-scale test a laptop was used to communicate with the cool unit, using a driver designed by Carrier U.S. Output of the unit was read and stored on the laptop and used to determine the temperature setpoint changes. Additionally, setpoints for heaters and fans were given. The container was loaded with one pallet with green and one with red peppers. To have a fair comparison with a fully loaded container, the effect of the flow resistance, heat production and moisture loss of 18 pallets of bell peppers were simulated. Airflow resistance was simulated by covering the T-bar floor of the container with a board with openings, heat production of 1 kW by artificial heating and the moisture loss by using evaporators.

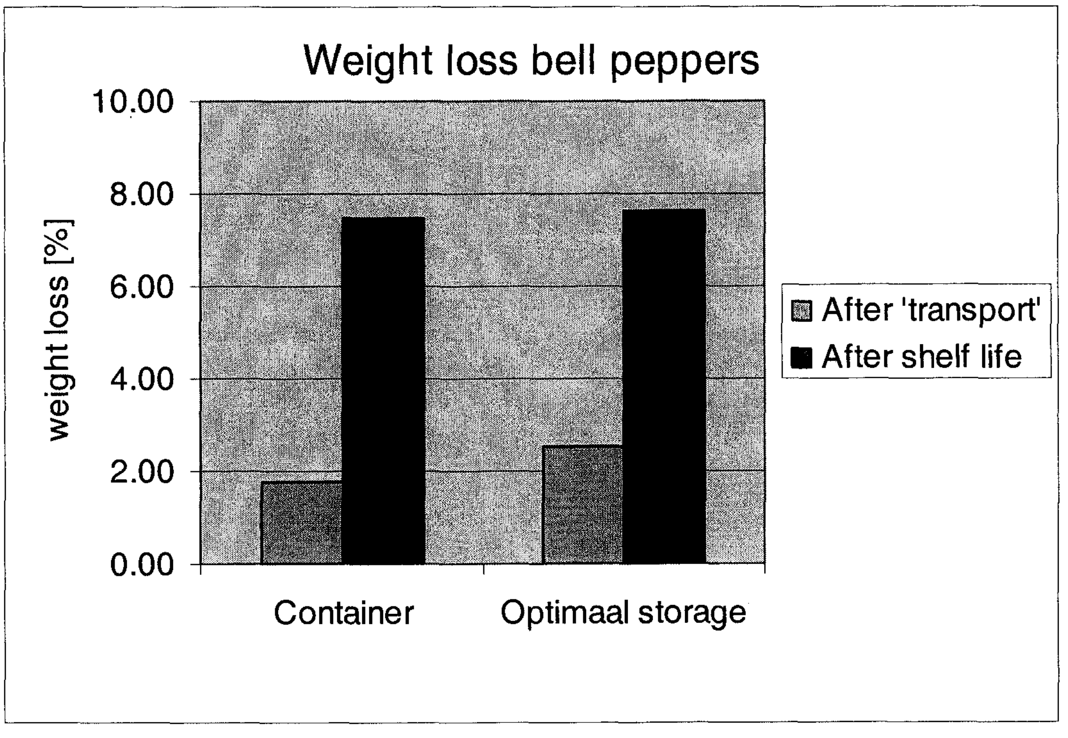
During the test the temperature and RH were measured in the boxes (layer 1, 4, 7 and 11) and in the airflow.

The results of the test showed that the climate in the unit was successfully controlled by the new software. Energy savings were calculated to be up to 50%.





Product quality
After transport the bell pepper quality of product at different locations in the stacks was compared to the quality of the bell peppers stored under optimal conditions, 8°C and 95% relative humidity. The quality aspects were firmness, as being related to weight loss, decay, low temperature problems and colouration of the green peppers. Weight loss during the simulated transport and optimal storage followed by different periods of shelf life is depicted in the figure below. There is no difference in weight loss, and therefore in firmness, between the container or the optimal regime. Stem decay was not more severe than compered to the optimal storage conditions expressed in number of affected fruit. However, the level of decay was higher. Fruit decay was not present. The temperature measurements showed that the box air temperature was always above 7°C. The bell peppers in the container showed no signs of decay induced by low temperatures. After container storage 2 of the 75 checked peppers showed colouration, increasing to 4 after 4 days of shelf life. The peppers stored at optimal conditions showed no colouration.
In short, no significant differences were found between optimal storage and the container regarding product quality. There was no comparison possible with a regular container.



Conclusions full-scale test QUEST regular
- the climate conditioning unit has been successfully controlled
- energy savings for climate conditioning of up to 50 % can be achieved
- bell pepper quality in QUEST regular climate control was comparable to quality under optimal storage conditions

2.2 Difficulties and solutions

Some of the project partners do not have a time registration system that can be used for this project. Therefore, the partners have received a form to register the hours of the employees working on the QUEST project.

2.3 Internal reports

The internal reports and presentations are available on request submitted to the project manager R. van den Boogaard at ATO. For the participants of the projects these documents can be addressed via the web-site of the project: http://www.ato.dlo.nl/quest/index.asp

Papers
- Product choice QUEST, discussion paper (ATO)
- Opportunities for energy savings for refrigerated containers, discussion paper (ATO)
- A preliminary classification of fresh products based on transport conditions, discussion document (ATO)
- Preliminary classification including import/export volumes, discussion document (PON)
- QUEST Selection of products and markets, and market introduction strategy, discussion document (ERBS)
- Summary avocado properties (ATO)

Presentations
- Kick-off QUEST, 31 October 2002
- Milestones QUEST, November 2002
- Energy Savings, Progress meeting 30 January 2003
- Product Classification, Progress meeting 30 January 2003
- Practical Guidelines, Progress meeting 30 January 2003
- General Progress, Management Meeting 27 February 2003
- Container test March, Management Meeting 27 February 2003

2.4 External reports

Automatic produce quality monitoring in reefer containers, L.J.S. Lukasse, M.G. Sanders, J.E. de Kramer. ATO, Wageningen, The Netherlands. Abstract. Quality In Chains, An Integrated View on Fruit and Vegetable Quality, Third International And Multidisciplinary Conference, Wageningen, 6-9 July 2003

3 Conclusions

3.1 Project realisation

The first full-scale test with a partially loaded container with bell pepper showed that product quality could be maintained while energy use for climate conditioning is reduced up to 50%. The first full-scale test in real transport will be carried out in the next phase of the project. If this technology can be made suitable for a wider range of products, it is very likely that the project goals will be met.

Appendix 1: Milestones QUEST

Key Milestones

- Inventory phase
  - February 2003, Test Quest-regular controller at container level (at ATO, no full load)
- Research phase
  - August 2003, full scale container tests with Quest-regular controller, Dutch produce
  - February 2004, full scale container tests with Quest-regular controller, foreign produce
  - August 2004, Test Quest-pro controller at container level (at ATO, no full load)
- Integration phase
  - February 2005, full scale container tests with Quest-pro controller

Milestones - Inventory phase February 2003

- Selection of products and markets
  - Select products (market share, profit, feasibility)
- Market introduction strategy
  - Definition unique selling points (energy? product knowledge?)
  - Pilot test: contact parties relevant for market introduction (relevant partners, relevant markets)
- Predictive models
  - Energy saving options (circulation, ventilation, defrost)
  - Temperature differences in space and time (effects of box, stowage)
  - Effects on product (cycling, condensation, weight loss, other quality aspects)

Milestones - Inventory phase February 2003

- Monitoring system
  - What to measure (weight loss, ethylene, respiration)
  - How to measure (moisture balance, electro chemical?)
- Control system
  - Structure ready (possibilities to use for other parameters)
  - Stable controller (the controller in control, instead of the operator)
- Practical guidelines
  - Choose design tool ("chain oriented design" Aladin?)
  - Determine set-up (web interface? book? table?)
  - Interaction with researchers (relevant data/models for guidelines)

Milestones - Inventory phase February 2003

- Chain information and technology transfer
  - Inventory present situation (what is happening now?)
  - Options for application of new technology (where can Quest knowledge be introduced?)
- Testing and integration
  - Test Quest-regular controller at ATO

Milestones - Research phase August 2003

- Selection of products and markets
  - Selection of Quest-pro product
- Market introduction strategy
  - Pricing
  - Benefits and risks
- Predictive models
  - Initial quality (what is that, how too handle it)
  - Quest-pro models (what can we do, how can we incorporate it)
  - Packaging and stowage (what are the effects, can we measure something in the container)
- Monitoring system
  - Quest-pro sensors (ethylene, respiration/heat production, waterloss)

Milestones - Research phase August 2003

- Control system
  - Quest-pro prototype
- Practical guidelines
  - Demo version (realistic data as far as possible, initial quality, package, stowage)
  - Feedback from experts
- Chain information and technology transfer
  - Working with Quest-regular in practical situation
- Testing and integration
  - First real life trip with Quest-regular (Dutch bell peppers to America)

Milestones - Research phase February 2004

- Selection of products and markets
  - Finished
- Market introduction strategy
  - Select markets
- Predictive models
  - Extending product models to a wider product range
  - Quest-pro models for controller
- Monitoring system
  - monitoring ready for Quest-pro

Milestones - Research phase February 2004

- Control system
  - Quest-regular control in the unit controller
- Practical guidelines
  - Feed-back from users
- Chain information and technology transfer
- Testing and integration
  - Tests Quest-regular container scale with Dutch produce
  - Test Quest-regular container scale with foreign produce
  - Test Quest-pro lab scale (at ATO)

Milestones - Integration phase February 2005

- Testing and integration
  - Tests Quest-regular container scale with foreign produce
  - Full scale practical tests with Quest-pro

Milestones - Integration phase August 2005

- Selection of products and markets; Finished
- Market introduction strategy; Finished
- Predictive models; Finished
- Monitoring system; Finished
- Control system; Finished
- Practical guidelines; Finished
- Chain information and technology transfer; Finished
- Testing and integration; Finished